New Results of Ground Target Based Calibration of MOS on IRS

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ABSTRACT

The success of the Modular Optoelectronic Scanner MOS on the Indian Remote Sensing Satellite IRS-P3 during the 6 years mission time has been based on its sophisticated in-orbit calibration concept to a large extent. When the internal lamp and the sun calibration failed in September 2000 we tested the possibility of ground target based (or vicarious) calibration of the MOS instruments to continue the high data quality. This is essential for future watching of global changes of the ocean coastal zones (phytoplancton, sediments, pollution, etc.) using spectral measurements of the VIS/NIR MOS spectral channels.
The investigations have shown the suitability of a part of the Great Eastern Erg in the Sahara desert for this purpose. The satellite crosses this very homogeneous area every 24 days. Because of the good cloudfree conditions we can use 6 - 8 overflys a year for calibration. The seasonal variability of the surface reflectance is very small so that we obtain relative calibration data of sufficient accuracy even without ground truth measurements for most of the channels.
The trend of this “vicarious” calibration corresponds very well with the previous trend of the failed lamp and sun calibration. Differences between the three methods will be discussed.
In the paper we will also present the results of a comparison between SeaWiFS and MOS data of comparable spectral channels from the Great Eastern Erg area. They confirm the suitability of this area for calibration purposes too.

Keywords: in-orbit calibration, ground target based calibration, imaging pushbroom scanner, VIS/NIR remote sensing, earth observation

1. INTRODUCTION

In September 2000 the two on-board calibration methods, both the internal lamp and the sun calibration, of the DLR’s Modular Optoelectronic Scanner MOS[1] on the Indian Remote Sensing Satellite IRS-P3 failed. Since then we have been using very successfully the ground target based calibration of most of the MOS spectral bands for checking the relative changes of their radiometric sensitivity, the water vapor affected bands excepted. Thus we get current recalibration data for these spectral bands. By interpolation we can also estimate calibration data for the remaining bands.
The ground target area used is a 30 x 30 km² part of the Great Eastern Erg in the Sahara between Tunisia and Algeria. Since October 2001 the SeaWiFS team is routinely extracting this region too, thus we are able to compare both the MOS and the SeaWiFS data over this region.
The calculations for MOS were made over a 60 x 60 pixel region, for SeaWiFS the calculations were made on the 4-km subsampled dataset over a 7 x 7 pixel region, both centered on 8.056 E and 32.439 N.
We investigated the MOS raw data corrected for earth-sun distance and solar zenith angle as well as the MOS and SeaWiFS surface reflectance additionally corrected with the SeaWiFS algorithm for Rayleigh, ozone, water vapor, oxygen, diffuse transmittance, and solar pathlength. The correction does not include scattering or absorption by aerosols.
For the MOS data calculation the ground target region was required to be absolutely cloudfree, also in the surrounding area. For the SeaWiFS data calculation an upper limit of 0.11 in the 412 nm surface reflectance was used as a cloud mask and the ground target area was required to be more than 50 % filled with unmasked pixels.

Table 1 lists the MOS and SeaWiFS sensor data whereas the MOS bands are restricted to the SeaWiFS-like bands.

MOS-IRS / DLR		**SeaWiFS / NASA**	
Instrument spectral bands (for MOS only SeaWiFS-like bands)			
B01	412 ± 5 nm	1	412 ± 10 nm
B02	443 ± 5 nm	2	443 ± 10 nm
B03	485 ± 5 nm	3	490 ± 10 nm
B04	520 ± 5 nm	4	510 ± 10 nm
B05	570 ± 5 nm	5	555 ± 10 nm
B08	670 ± 5 nm	6	670 ± 10 nm
B09	750 ± 5 nm	7	765 ± 20 nm
B11	865 ± 5 nm	8	865 ± 20 nm
Mission characteristics			
Swath width 200 km (14.0°)		Swath width 2800 km (53.8 °)	
820 km sun synchroneous orbit		705 km sun synchroneous orbit	
0.52 x 0.52 km² pixel size		1.1 x 1.1 km² pixel size	
10:30 AM equator crossing, descending		12:20 AM equator crossing, descending	
24 days revisit time		1 day revisit time	

Tab. 1: MOS and SeaWiFS sensor description (MOS only SeaWiFS-like bands)

Unfortunately we do not have ground truth measurements of the test site for checking and comparing the in-situ surface reflectance with those derived from the MOS and SeaWiFS data. But we can compare our satellite data with BRDF measurements of Sahara sand from Tunisia made by D. Despan[2,3] in September 1997 at the European Goniometric Facility (EGO) of the Joint Research Centre at Ispra/Italy.

2. Ground Target Conditions

The part of the Great Eastern Erg in the Sahara desert used for the MOS ground target based relative calibration is a very homogeneous area with good cloudfree conditions and a very small seasonal variability.
Because of the MOS revisit time of 24 days and mission scheduling of the IRS-P3 satellite we could use 32 overflights for calibration purposes during May 1996 and February 2002. The solar zenith angle varies from 16° to 61° during this time (equator crossing at 10:30 AM), the viewing zenith angle is about 3° and the solar azimuth angle varies between 155° and 165°.
From the SeaWiFS instrument we could use about 1000 measurements of the test area during September 1997 and February 2002 due to the 1 day revisit time. The SeaWiFS viewing conditions are somewhat different to the MOS viewing conditions. The solar zenith angle is smaller because of the equator crossing time of 12:20 AM and the solar azimuth angle is closer to 180°. The variability of the viewing zenith and azimuth angle is higher than for MOS because of the large SeaWiFS swath angle of 53.8°.
The BRDF measurements of Sahara sand by D. Despan at the EGO are very helpful for interpreting the satellite measurements over the Great Eastern Erg from MOS and SeaWiFS. The EGO measurements were made for both smooth surfaces and rough surfaces because the spatial distribution of light scattered by a natural surface is influenced by its roughness profile by tilting the tangent plane and shadowing. The roughness profile of the Computer Numerical Control generated mould was Gaussian with Gaussian autocorrelation function with elevation r.m.s. = 5 mm and correlation length = 12 mm.
Fig. 1a, 1b and 1c show the BRDF plots of Sahara sand[4] at 520 nm, 606 nm, 700 nm, 801 nm, 900 nm and 1000 nm for solar azimuth angle of 0° and for different solar zenith angles of 27°, 47° and 67°. The relative viewing azimuth is counted clockwise from 0° (below) to 360°, the dashed circles in the diagram are for 30° and 60° viewing zenith angle. The left part of the figures shows the BRDF of the smooth surface and the right part shows it for the rough surface. We find a high symmetry of the BRDF values for smooth surfaces at all three solar zenith angles. The rough surface shows a quite different behaviour, the higher the solar zenith angle, the higher the asymmetry of the BRDF values (strongly dependent on relative viewing azimuth and viewing zenith).

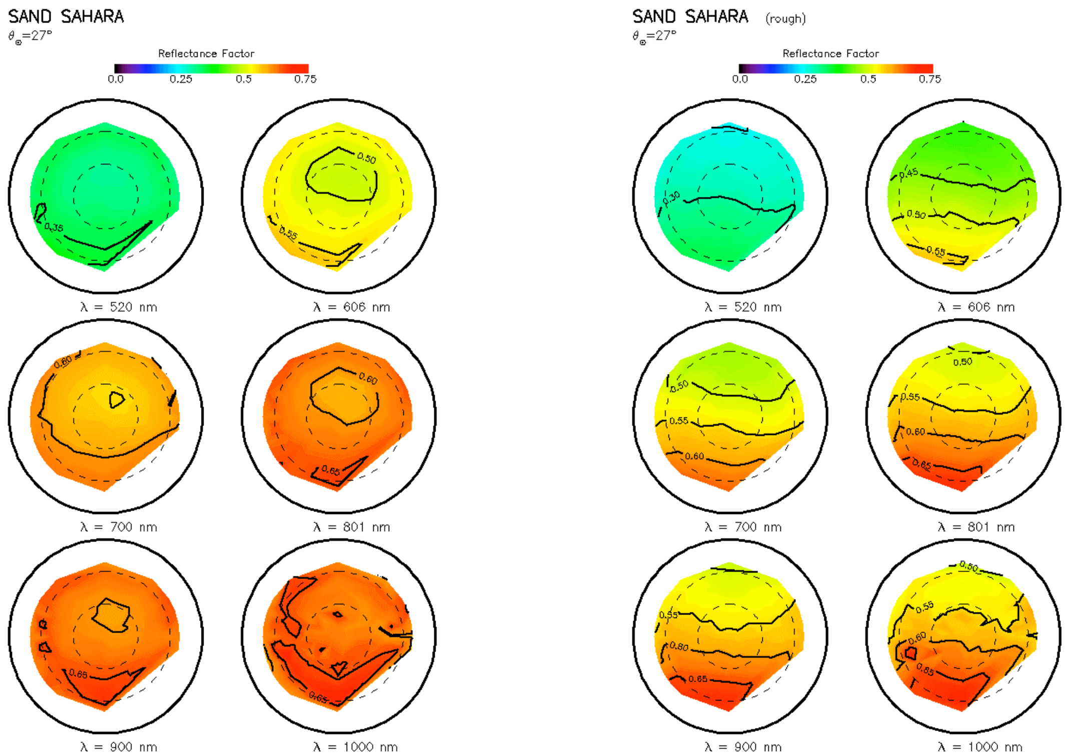


Fig. 1a: BRDF of Sahara sand, solar azimuth angle 0°, solar zenith angle 27° (measured by D. Despan, plots from ref. 4)

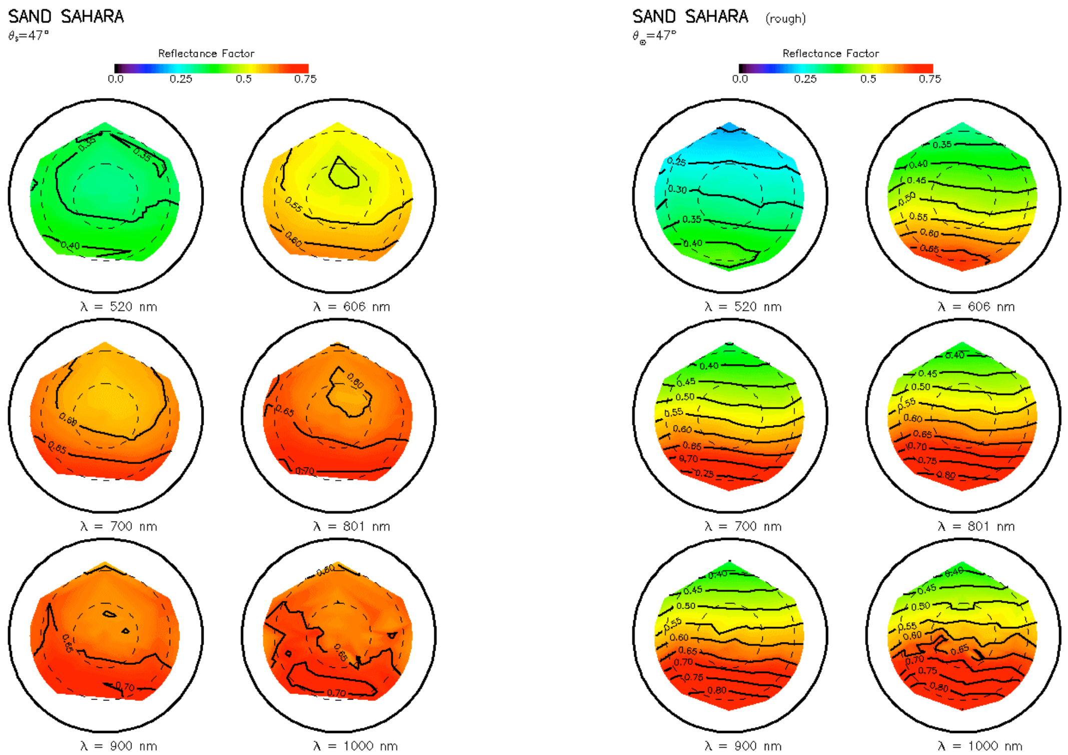


Fig. 1b: BRDF of Sahara sand, solar azimuth angle 0°, solar zenith angle 47° (measured by D. Despan, plots from ref. 4)

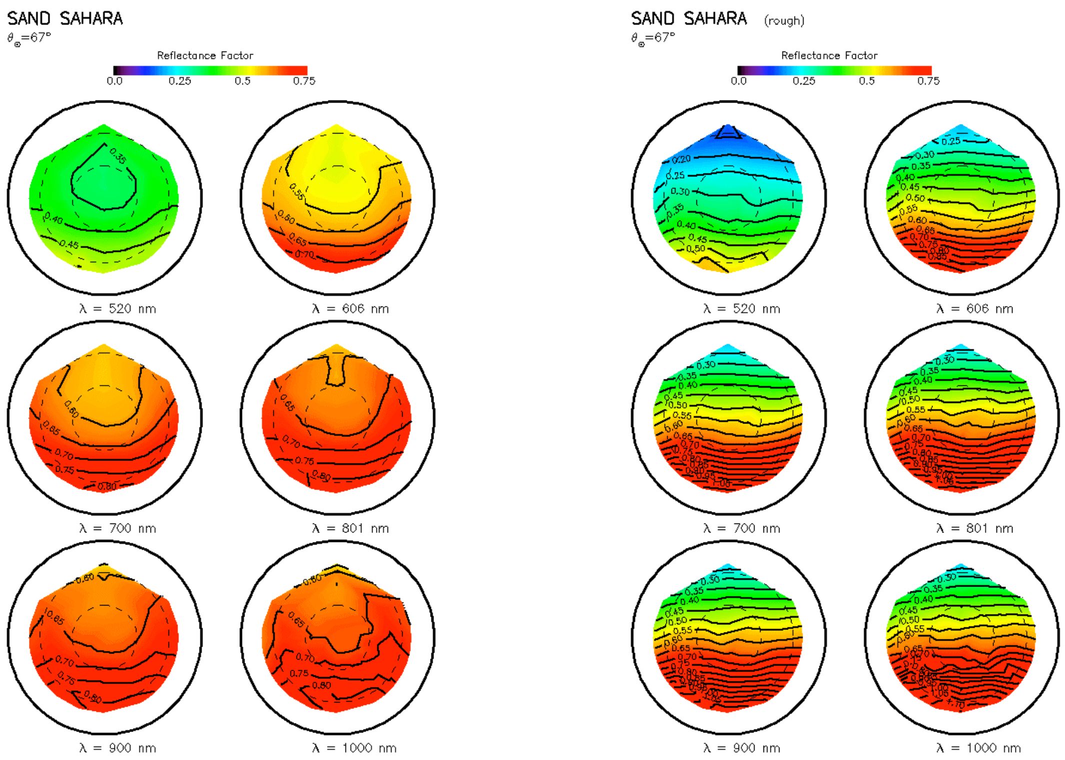


Fig. 1c: BRDF of Sahara sand, solar azimuth angle 0°, solar zenith angle 67° (measured by D. Despan, plots from ref. 4)

Fig. 2 shows the correspondent surface reflectance at the MOS and SeaWiFS spectral channels for solar zenith angles of 27°, 47° and 67° at satellite like viewing conditions (solar azimuth angle 0°, relative viewing azimuth 180°, viewing zenith angle 10°).

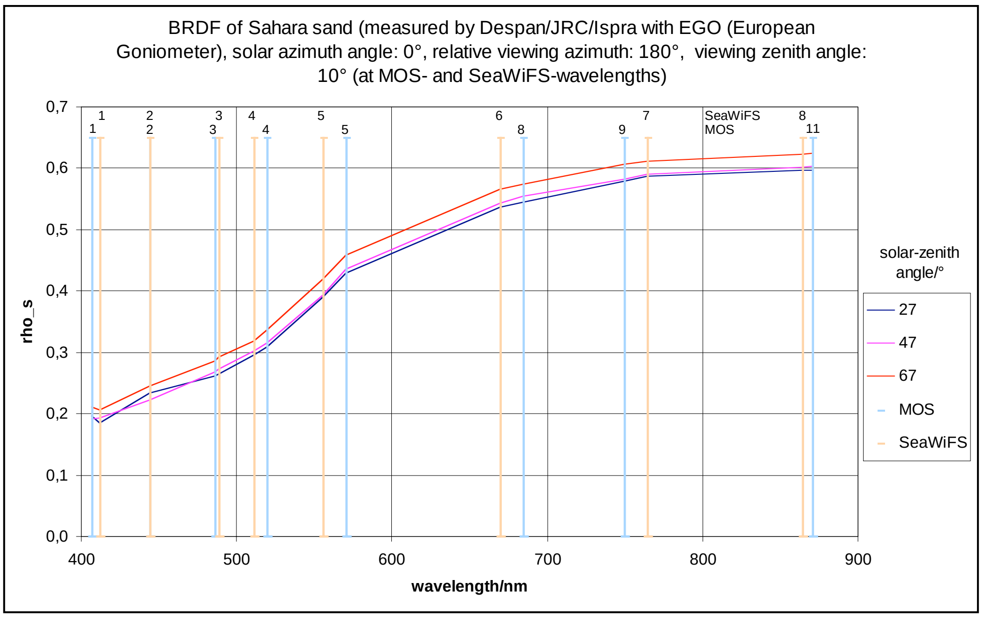
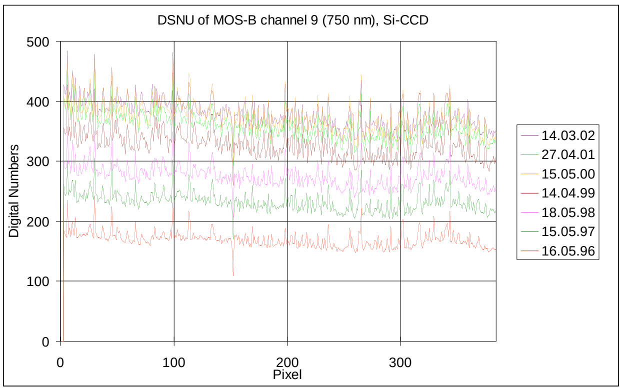


Fig. 2: Surface reflectance of Sahara sand at the MOS and SeaWiFS spectral channels for solar zenith angles of 27°, 47° and 67° (measured by D. Despan)

3. RESULTS OF THE MOS CALIBRATION

3.1 Instrument performance, DSNU and PRNU

The high performance of the MOS instrument, both the optomechanical and the electronical part, has been demonstrated through the 6 years mission time. We did not find any pixel failure and the temperature at the detectors remains inside the stabilisation band of 5.0 $\pm$ 0.05 °C. This temperature stability guarantees that we can exclude temperature induced dark signal variations and response changes (the Si-CCD sensors have a maximum response variation of 1% per 1°C at 1000 nm).
The dark signal level of all channels increases differently in a nearly linear manner, the DSNU (Dark Signal Non Uniformity) has similar curves for the pixels of each channel at different times. Fig. 3 shows the development of the DSNU of the MOS channel B09 as an example. After the failure of the internal lamp and the sun calibration in September 2000 the dark signals were measured on the night side of the earth.
The PRNU (Photo Response Non Uniformity) of each channel changes as a function of time too but nearly proportionally for all pixels of each channel. Fig. 4 shows this for the MOS channel B09 as an example too. The PRNU curves were derived from the sun calibrations between May 1996 and September 2000 (13.02.2002 from Sahara data).



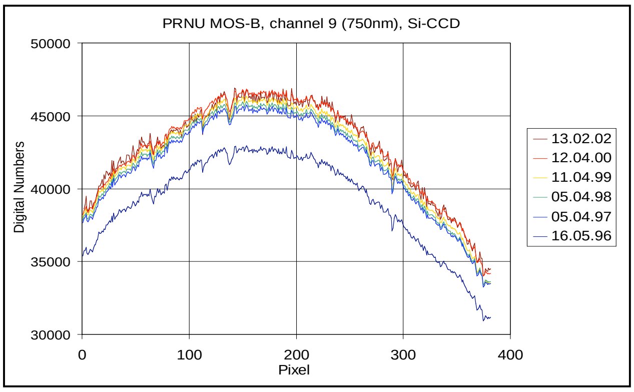
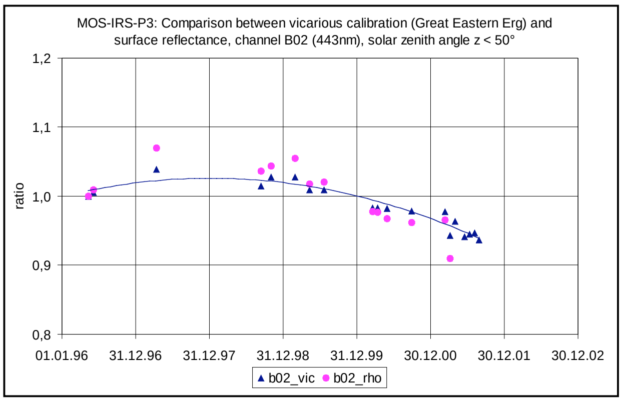


Fig. 3: DSNU of MOS channel B09

Fig. 4: PRNU of MOS channel B09

3.2 Time trend of ground target based MOS calibration

The relative time trend of the different MOS-B channels first was derived from the raw data only corrected for earth-sun distance and solar zenith angle (May 1996 = 1.0). The solar zenith angle was required to be smaller than 50° to reduce effects caused by roughness profiles, shadowing and possible hoarfrost in winter. In the second step we investigated the possibility of further refinement of these data by using the surface reflectance calculated with the SeaWiFS land algorithm (corrected for Rayleigh, ozone, water vapor, diffuse transmittance, solar pathlength, but not for aerosols) instead of the MOS raw data. The results are shown exemplarily for the channels B02 and B09 in fig. 5a and 5b.



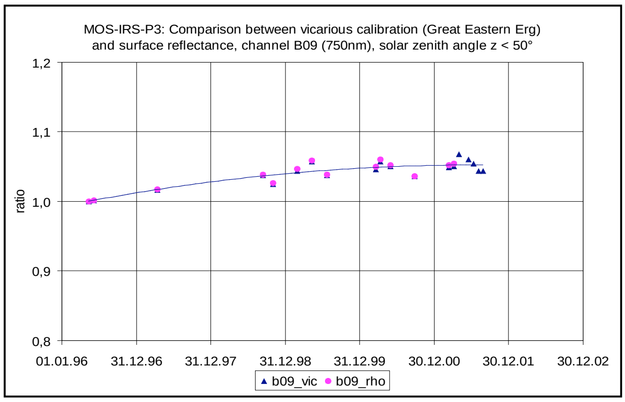
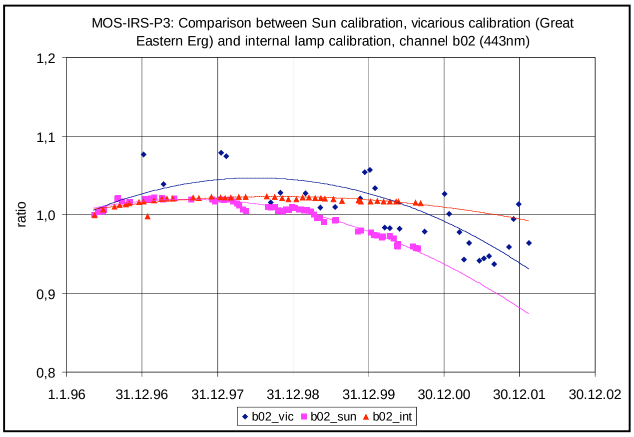


Fig. 5a, b: Time trend derived from target based raw data (vic) and surface reflectance (rho), a) channel B02, b) channel B09

We found that the surface reflectance values give nearly the same trend curves and do not reduce the scattering of the data. We got an even higher scattering then without the correction for the shorter wavelength channels up to 485 nm. That means we can derive relative calibration data of good accuracy using this test area with the requirements made and without ground truth measurements.
Comparing the time trends of the ground target based calibration (here no limitation of the solar zenith angle) and the sun and internal lamp calibration (the two last calibration methods up to its failure in September 2000) we see that the previous time trend is continuing. The differences in the short wavelength spectral channels B01…B04 especially are caused by the different optical principles of the 3 calibration methods[5], for the longer wavelength channels the consistency is much better. The accuracy (that means the scattering of the calibration data around the trend curve) of the 3 methods is different too, about 0.3% for the internal lamp calibration, 0.5% for the sun calibration and up to 3% for the ground target based calibration if we do not limit the solar zenith angle (water vapor influenced channel B10 and B12 are excluded). But the ground target based calibration should show the most realistic development of the relative responsivity of the spectral channels as long as the spectral characteristic of the test area does not change. Fig. 6a and 6b show all this exemplarily for channel B02 and B09.



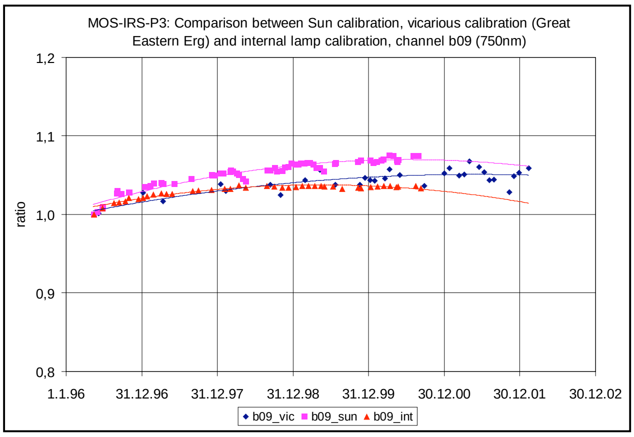


Fig. 6a, b: Time trend of target based (vic), sun (sun) and internal lamp (int) calibration, a) channel B02, b) channel B09

4. COMPARING THE RESULTS BETWEEN SeaWiFS AND MOS

We will now compare the reprocessed SeaWiFS data and the MOS data of the common test area in the Great Eastern Erg (see also ref. 6). The relative variations of the SeaWiFS data are derived from surface reflectances using the SeaWiFS land algorithm (cloud masked scenes are included). Fig 7b, d and f show these relative variations normalised to an arbitrary date in May 1998 for the SeaWiFS channels 2, 5 and 7. The MOS data are derived from raw data only corrected for earth-sun distance and solar zenith angle. Fig. 7a, c and e show the deviation of all MOS cloudfree test site measurements from the fitted curve of the time trend (second order polynom) for the correspondent three MOS channels B02, B05 and B09.
The main reason for the higher variation of SeaWiFS data is the use of all cloud masked scenes too. In general we find higher variations in the short wave channels because of the lower surface reflectance values and the higher atmospheric contribution to the signals. Both the MOS and SeaWiFS data show clearly seasonal variations (more pronounced by the great number of SeaWiFS data) obviously caused by different solar zenith angles, that means shadowing and tilting of the tangent plane of the roughness profile and general deviations from a cosine behaviour of the surface reflectance. But from the strong reproducibility of this periodical structure during 6 years we can assume a high stability of the spectral charactristics of this test area.
The differences between MOS and SeaWiFS data visible on fig. 7, not only in the dynamics of the periodic curves but also in its phase, are caused by the different viewing geometry of MOS and SeaWiFS. The solar zenith angles are different because of about 2 hours difference in the equator crossing time between the two sensors (see tab. 1). And fig. 1a…c demonstrates the high variability of the BRDF of a profiled sand surface with respect to the viewing zenith and azimuth angle which are quite different for MOS and SeaWiFS. The greater the solar azimuth angle the stronger the effect of the viewing and azimuth angle onto the BRDF.

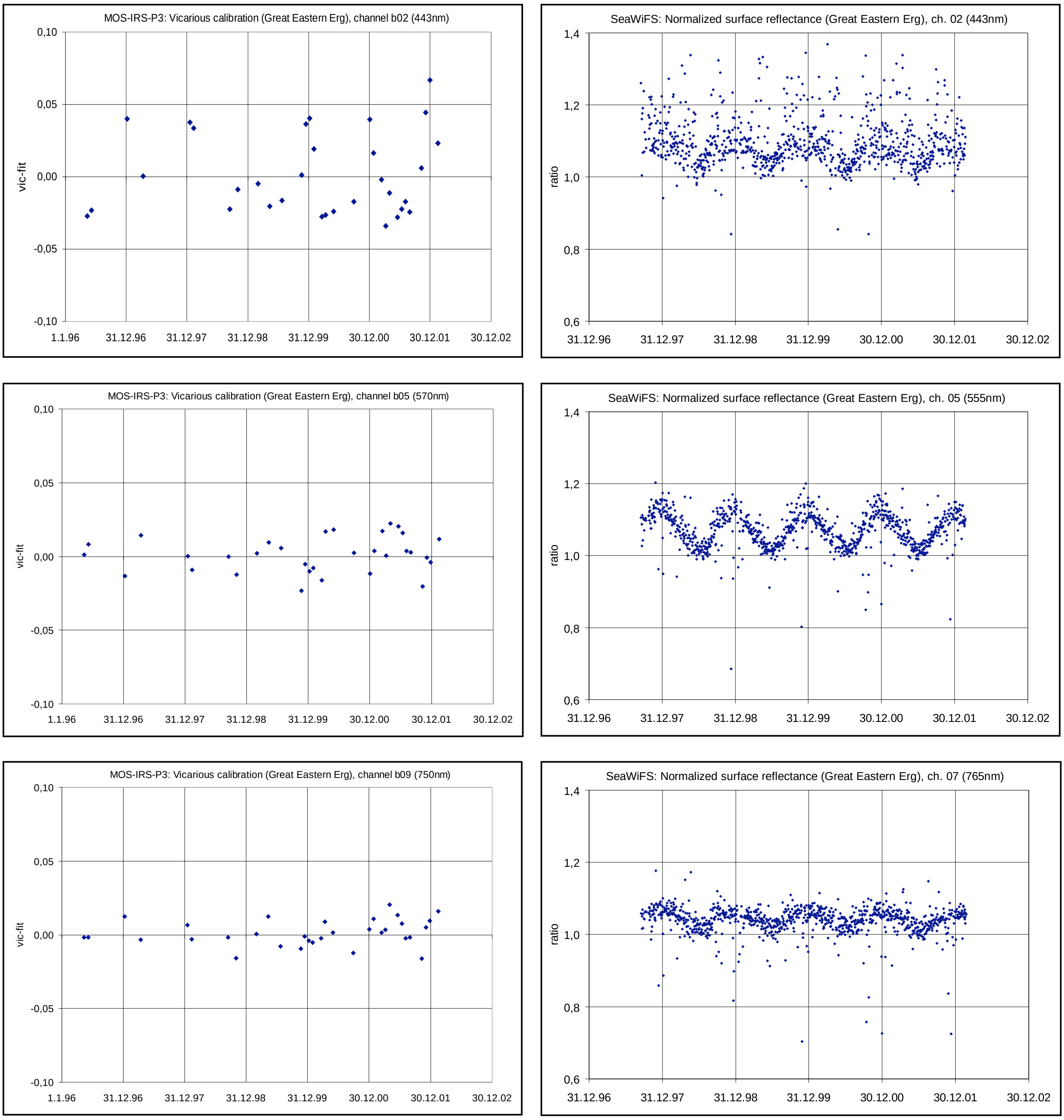


Fig. 7a…f: Relative variations of recalibrated MOS and SeaWiFS data of Great Eastern Erg test site for three selected channels with similar wavelength (left column MOS: B02, B05, B09; right column SeaWiFS: 2, 5, 7)

We also find some differences in the spectral characteristics of the reflectance curves of the common test site, shown in fig. 8a and 8b, which can not have their reason in the different viewing geometry of MOS and SeaWiFS (see also the spectral reflectance of Sahara sand by Despan, fig. 2). The differences are very distinctive especially around 750 nm. The MOS channel B09 at 750 nm with its FWHM of 10 nm is completely outside the oxygen absorption band near 760 nm but the SeaWiFS channel 7 at 765 nm with its FWHM of 40 nm covers this spectral area, which may be the reason for this problem.

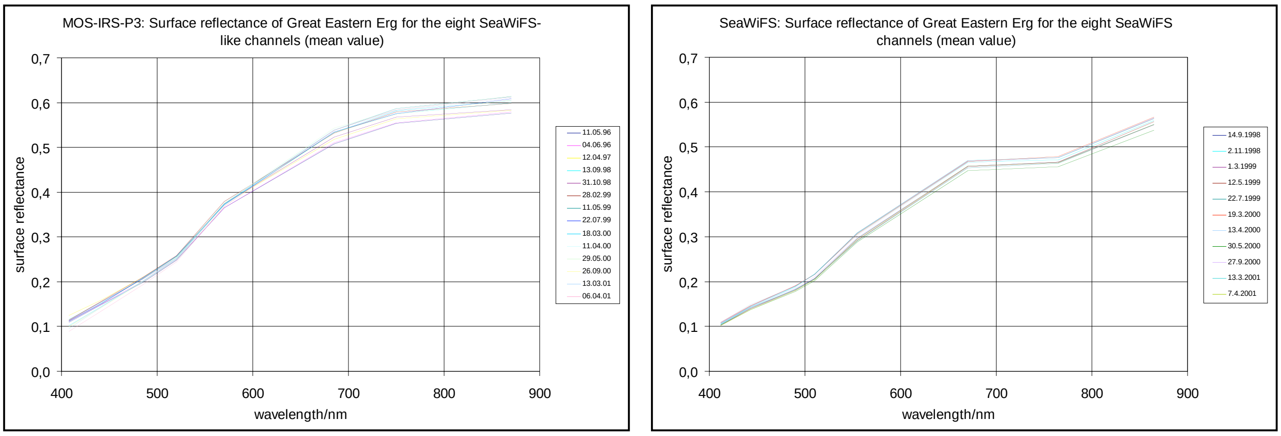


Fig. 8a,b: Spectral reflectance of Great Eastern Erg test area derived from a) MOS, b) SeaWiFS

These reflectance curves of the Great Eastern Erg test site from MOS and SeaWiFs are taken at cloudfree conditions and nearly at the same time. Both the MOS and the SeaWiFS reflectances are calculated with the above mentioned atmospheric corrections, the standard deviation of the data is not significantly different.

5. ACCURACY OF THE MOS GROUND TARGET BASED CALIBRATION

Because we no longer have alternative in-orbit calibration possibilities of MOS (lamp or sun calibration) with sufficient accuracy it is necessary to refine the ground target based calibration as well as possible. When we have a look at the dependency of the differences between the fitted time trend and the ground target based calibration data (vic-fit) on the solar azimut angle we find that we can improve the accuracy by limiting the solar zenith angle to be smaller than 50°. It works especially for the shorter wavelength channels (up to channel B07). Fig.9a and 9b show it exemplarily for the MOS channels B02 and B09.

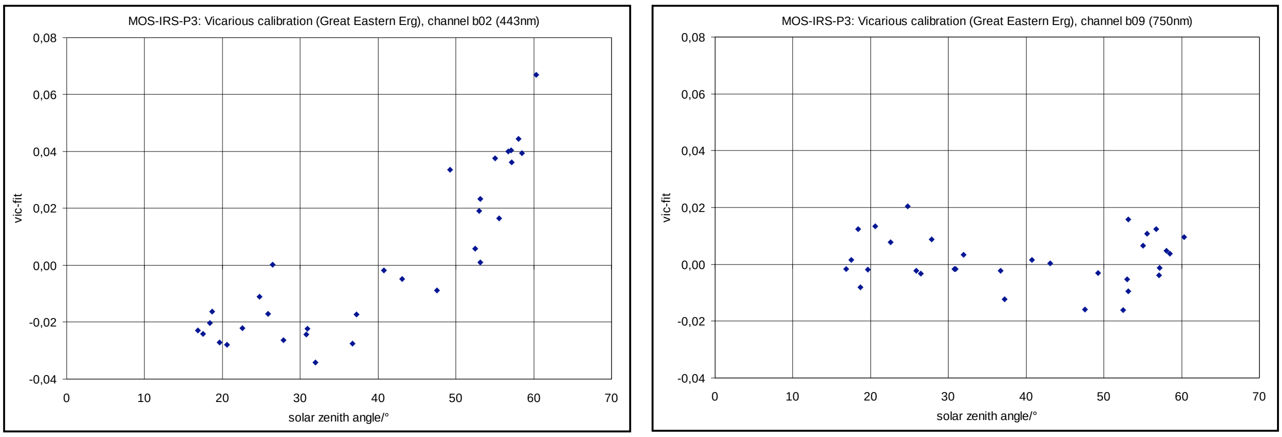
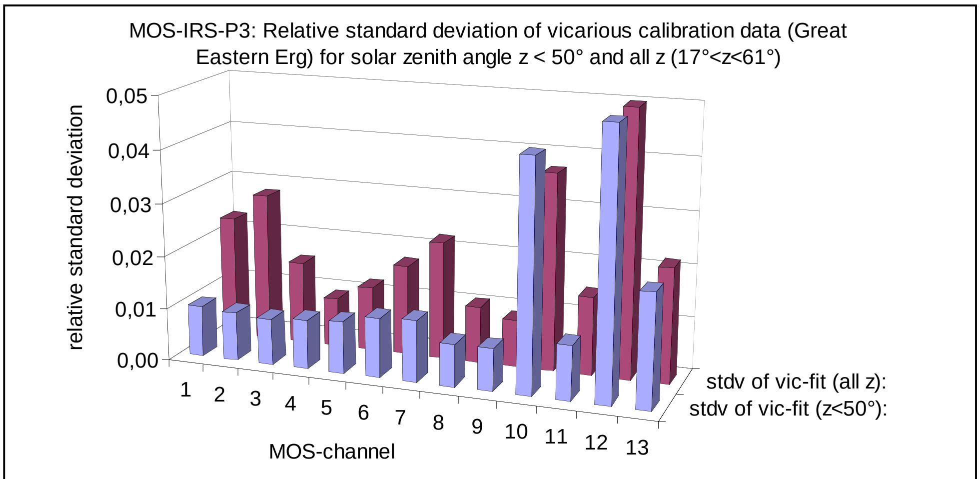


Fig. 9a, b: Differences between fitted time trend and ground target based calibration data (vic-fit) as a function of the solar azimut angle, a) channel B02, b) channel B09

Fig. 10 demonstrates the result of improving the accuracy of the ground target based calibration data by limiting the solar zenith angle for all MOS channels. We get an accuracy of the relative calibration data during the last 6 years in the order of 2% for channel B13 and 1% for all other channels, excepted the water vapor affected channels B10 at 815 nm and B12 at 945 nm.



	1	2	3	4	5	6	7	8	9	10	11	12	13
stdv of vic-fit (z<50°):	0,010	0,009	0,009	0,009	0,010	0,011	0,012	0,008	0,008	0,043	0,010	0,216	0,021
stdv of vic-fit (all z):	0,023	0,028	0,016	0,009	0,012	0,017	0,022	0,011	0,009	0,037	0,015	0,199	0,022

Fig. 10: Improvement of the accuracy of the ground target based relative calibration by limiting the solar zenith angle

6. CONCLUSIONS

The TOA (top of atmosphere) radiance measurements over the common test site in the Great Eastern Erg (Sahara) by SeaWiFS and MOS show the suitability of this area for ground target based (or vicarious) calibration of satellite sensors. The spectral reflectance characteristics show seasonal periodical variations mainly caused by different solar zenith angles and the involved effects of tilting the tangent plane and shadowing of rough surfaces. But these variations are very reproducible and confirm the high stability of the optical properties of the test area. We can reach relative calibration accuracies for most VIS/NIR spectral channels of a satellite sensor in the order of 1% over this part of the Sahara by limiting the solar zenith angle to be smaller than 50° and a strict selection of cloudfree overflights. The applied SeaWiFS land algorithm gives no further refinement of the accuracy of the calibration data.
Thus we can recalibrate the sensor channels (water vapor influenced channels excepted) with the same accuracy reached for the relative calibration by using the initial absolute radiometric calibration and the derived time trend from the ground target based measurements. Differences between the SeaWiFS and the MOS measurements are obviously caused by different viewing geometry and especially in the 750 nm spectral region by the different spectral FWHM of the two sensors (oxygen absorption band).

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